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(72) Inventors STANLEY PAUL BURG and
WILLIAM JOHN HENTSCHEL

(54) STORAGE OF METABOLICALLY ACTIVE MATERIAL

(71) We, GRUMMAN ALLIED INDUSTRIES INC., a corporation organised under the laws of the State of New York, United States of America, of 600 Old Country Road, Garden City, New York, N.Y. 11530, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the preservation of metabolically active matter, such as fruit, vegetables, flowers, foliage, and other plant material, including bananas, as well as meat and other desirably preserved organic matter.

One method of creating a beneficial preservation atmosphere in which the matter can be stored, taking into account all the factors of temperature, pressure, relative humidity, metabolic oxygen demand and disposal of gaseous metabolic effluents, is disclosed in U.S. Patent No. 3,333,967 wherein a suitable pressure, saturated water content and means for disposing of gaseous metabolic effluents were provided by the use of a flow-through vacuum chamber, the internal temperature of which was controlled by an independent closed circuit (closed cycle) refrigerating system, whereby the contents of the chamber are not exposed to the refrigerant.

It has now been found that by applying an open cycle system of refrigeration, in which the contents of the chamber are exposed to the refrigerant, to a water saturated air flow-through vacuum chamber system operating at rates of air flow and hypobaric pressures (preferably 4—400 mm Hg) conducive to organic matter preservation, an air cooling capacity can be created which is more than sufficient, consequent on expansion of the air and evaporation of water, to care for operation at optimal internal temperatures of 32°F or above even when encountering the maximal expected temperatures of ambient air input, say up to 120°F. Closed cycle refrigeration and its attendant weight and cost may be completely or partially eliminated as operating conditions may permit or require.

According to one aspect of the present invention there is provided a method of creating and maintaining a gaseous atmosphere at a predetermined temperature, subatmospheric pressure and high relative humidity in a storage chamber for preserving organic matter such as fruit, meat, vegetables, other edible food, plants and flowers from which gases may respire, the method comprising bringing ambient air to the required temperature, pressure and relative humidity by causing the ambient air to flow through a restricted opening while reducing the pressure of the air expanding the air and reducing the relative humidity thereof, causing the expanded air to flow into contact with water to evaporate the water, the expansion of the air and evaporation of the water cooling and humidifying the air, causing the humid air to flow through the chamber, and simultaneously removing humid air and gases of respiration of said matter from the chamber, wherein the cooling effect of the expansion and evaporation is modified by changing the temperature of the water when the temperature of the air in the chamber tends to depart from the predetermined temperature.

According to another aspect of the present invention there is provided apparatus including a storage chamber for organic matter such as fruit, meat, vegetables, other edible food, plants and flowers from which gases may respire, and means for creating and maintaining a gaseous atmosphere in the storage chamber at a predetermined temperature, sub-atmospheric pressure and high relative humidity for preserving organic matter when in the chamber, the gaseous atmosphere maintaining means comprising pump means for removing air and gases of resporation from the chamber and for drawing fresh air into the chamber, a restricted

opening through which ambient air will be caused to flow by the pump means to reduce the pressures of the air cause the air to expand and reduce the relative humidity thereof, means for receiving a supply of water arranged so that expanded air from the restricted opening and to be supplied to the chamber will be brought into contact with water in the water receiving means to humidify the air, the arrangement being such that the expansion of the air and evaporation of the water will cool the air, and means responsive to the temperature of air in the chamber for modifying the cooling effect from the expansion of the air and evaporation of the water when the temperature of the air in the chamber tends to depart from the required temperature.

Modification of the cooling effect is readily accomplished in its simplest form by regulating heat input to the water in dependence on the output of a chamber temperature sensor so that whenever the required air temperature in the chamber is higher than would be obtained with application of the full cooling effect at the given rate of air flow and pressure, the cooling effect is overridden to the extent required to attain and maintain optimal air temperature in the chamber, throughout the whole range of ambient temperature e.g. from 120°F down to −20°F or lower.

Such heat input may be provided by an electric resistance heater placed in the body of water or alternatively, by heat exchange thereof with the oil cooling system of an oil seal vacuum pump or the air or water cooling system of a water pump which creates the internal partial vacuum in the preserving chamber or with atmospheric air.

Advantageously the pressure of the air in the chamber is at or between 4 and 400 mm Hg absolute and the temperature is at or between 32°F and 58°F.

Embodiments of apparatus in accordance with the invention will now be described, by way of example only, with reference to the accompanying drawings, wherein:—

Figure 1 is a diagrammatic cross-sectional view of an embodiment of apparatus in accordance with the invention;

Figure 2 is a similar diagrammatic view of a portion of the apparatus shown in Figure 1 but utilizing a different and alternative form of heat input; and

Figure 3 is a diagrammatic cross-sectional view of another embodiment of apparatus in accordance with the invention and similar to that shown in Figure 1 except that the evaporator and other elements are located outside the chamber instead of inside as shown in Figure 1.

Figure 1 shows insulated walls 10 forming a vacuum storage chamber 12. An ambient air inlet 14 leads through a rotameter 15 for measuring air flow into an insulated heat exchanger diagrammatically shown at 16, through an air pressure reducing element shown as a valve 18 having a restricted opening and thence downwardly below the level of a body of vaporizable liquid 20 contained in a tank or tower forming an evaporator 22 which has an outlet 24 connected to its top and terminating in a tapered nozzle 26.

Air leaves the vacuum chamber through a valve 28 which controls the rate of air flow and is discharged into the heat exchanger 16 and thence to the vacuum pump 30.

The tapered nozzle 26 discharges towards a radiator 32 through which is circulated liquid from the body of liquid 20 in the evaporator 22 as by a pump 34.

A temperature sensor 36 is positioned adjacent the chamber outlet and is connected in a control circuit including a relay 38 which opens and closes electrical circuit 40 in which is included an electrical resistance heating element 44 positioned in the lower part of the evaporator 22.

A liquid replenishing system and liquid level control is indicated generally at 50. This can be a normal float bowl which opens the valve to a water inlet 52 to maintain a proper level of water in the evaporator 22. A desalting system is indicated at 54 which can be a Culligan reverse osmosis membrane filter followed in series by a mixed bed ion exchange resin. The water inlet is preferably under pressure but if only a reservoir is available, a booster pump may be inserted to provide the reverse osmosis filter with at least 40 p.s.i. water pressure.

The pressure reduction valve 18 has a range of 0—760 mm. Hg but for produce storage is set to operate in the range from 4—400 mm Hg (where 760 mm. Hg is atmospheric pressure). Temperature and pressure gauges are shown at 56 and 58 respectively.

The vacuum pump 30 being in operation, air is drawn through the inlet 14 and through the insulated heat exchanger 16. As the incoming air passes through the restricted opening of the valve 18, it expands, its pressure is reduced and it experiences a cooling effect.

Regardless of the initial relative humidity (R.H.) of the ambient air, the R.H. after crossing the pressure reduction valve is low because R.H. is decreased in direct proportion to the pressure drop, except that to some extent this is compensated for by the cooling effect. If further reduction in R.H. is desired to increase the refrigeration capacity, a heatless air dryer of a well-known commercial type can be installed at the inlet 14. Relatively dry air, now at a reduced pressure, passes down to the bottom of evaporator 22. The incoming air bubbles through the

body of water 20, causing water to evaporate and raise the vapor pressure of water in the outlet air stream to nearly saturation at the specific air temperature. The vapor pressure of water is independent of the operating pressure within the vacuum tank and evaporator, but depends upon the temperature so that less water is evaporated at lower temperatures and the cooling efficiency becomes progressively lower as the temperature is reduced. The evaporation of water creates a cooling effect which causes the water remaining in the evaporator to decrease in temperature, and this water is pumped by the water circulating pump 34 to radiator 32. The air passing through the evaporator is cooled in transit by the cool water in the evaporator and in addition as it leaves the evaporator its velocity is increased by the nozzle 26 which directs its flow across the radiator 34 where further heat exchange occurs.

Air leaves the vacuum chamber and passes into the insulated heat exchanger 16 by way of the valve 28 which controls the rate of air flow. This valve is siutated upstream of the heat exchanger 16 so that the pressure drop across the valve will produce an additional cooling effect in the heat exchanger. The valve can also serve to reduce the pressure at the vacuum pump inlet to approximately 30—40 mm. Hg, which in the case of an oil seal pump is ideal for venting water vapor from the oil. An oil seal vacuum pump is well suited for use when the container is carried on a flatbed trailer or railcar, but a water seal pump or other type might be preferable in a shipboard installation, or during use of the method at a stationary location.

The internal temperature of the vacuum chamber is regulated by heater 44 located in the evaporator. The heater is turned on and off responsive to sensor 36 and as required to maintain a desired temperature.

During a cooldown operation, the vacuum pump may be operated at maximum capacity to produce the full refrigeration effect, the greater the air flow, the greater the refrigeration effect. After operating conditions are established and especially when an operating temperature above ambient is required in the vacuum chamber, this rate can be reduced by adjusting the regulating valve to restrict flow therethrough. When it is desired to operate under conditions which lower the temperature of the liquid body to 32°F. or lower, the liquid body must have a correspondingly still lower freezing point, as by adding a non-volatile anti-freeze component to water. Where there is excess cooling caused by a low ambient temperature, the heater must have sufficient capacity to raise the temperature of the incoming ambient air and overcome the ever present cooling effect of the vacuum refrigeration system. On a heating cycle, the insulated heat exchanger assists the heater just as it does the refrigeration system by conserving work accomplished.

In Fig. 2, an oil seal pump is used to produce the vacuum. The pump oil then serves as the heat source. Oil from the vacuum pump oil reservoir 60 is sucked from the vacuum pump by oil pump 62 and forced into a heat exchanger 64 passing through two solenoid operated valves 66, 68 which can direct the flow toward the heat exchanger 64 until the temperature sensing element (36 in Figure 1) calls for heat input. When this happens, the hot oil is directed by the valves, actuated from the sensor, through a pipe 70 which passes through the body of water 20 in the evaporator 22, thus heating the water in the evaporator. In the heat exchanger 64, the oil is reduced in temperature before returning to the vacuum pump reservoir 60. The heat is transferred in exchanger 64 to water and dissipated in a radiator 72 cooled by fan 74. Leaving the radiator the water returns to a reservoir 76 from which it is pumped by a water pump 78 to the heat exchanger 64. The water pump 78 is actuated by a relay in a control unit 80, which in turn is actuated by a temperature sensing probe 82 located in the oil reservoir. In this way, the oil temperature can be maintained at about 145°—150°F., the most favorable temperature for venting water from the oil since higher temperatures accelerate oil decomposition and breakdown of the filter element 84 in the oil mist eliminator 86 associated with the vacuum pump 30. The mode of operation of the pump, with an inlet pressure of about 30—40 mm. Hg. an oil temperature of 145°—150°F. and a continual bleed of aid ensures that the water vapor can be effectively exhausted by the vented exhaust oil seal pump.

If a water seal pump is employed, a heat exchanger can transfer the heat from the sealing water to some other cooling medium (water, air, or some other fluid). The exchanged heat may then be used to supply heat to the evaporator by means analogous to those illustrated for the oil of an oil seal pump in Fig. 2. Other types of vacuum pumps also produce heat during operation, which may be used for heating the evaporator.

An alternative vacuum refrigeration system, in which all components are located external to the vacuum tank, is illustrated in Figure 3. The control equipment is all located in an air tight insulated space 100 separated by a heat-transmitting finned wall 101 from the insulated vacuum chamber, included as an integral part of the container.

Ambient air enters at inlet 14a and passes through a heat exchanger 16a. Its temperature is lowered or raised depending upon whether the system is heating or cooling. The air then exits at 117 to circulate freely in space 100 containing the equipment and enters the rotameter 118, from whence it passes across pressure regulating device 18a which may reduce the pressure to about 25 to 250 mm. Hg. This produces a cooling effect, and also lowers the R.H. of the air. The air then flows through pipe 119 to the bottom of the evaporator 22a and bubbles through the body of water 20a contained in the evaporator. The evaporation of water saturates the air at the specific temperature prevailing in the evaporator and produces a cooling effect during this operation. The air is then led through conduit 24a and enters the vacuum tank through a tapered nozzle 26a which increases its flow rate and lowers its pressure producing marked circulation and cooling in the tank. Air exits from the tank, passing through flow regulating valve 28a into the heat exchanger 16a where it assists in cooling (or heating) the incoming ambient air. As the air crosses valve 28a the pressure reduction, if any, may produce a further cooling effect which is transmitted to the incoming air. Water from the evaporator 22a is circulated through a radiator 32a by means of a water pump 34a. A fan 121 forces air across the radiator 32a and thus cools or heats the air in the instrument compartment before it enters rotameter 118. The water entering the evaporator 22a is desalted at 120 and kept at an appropriate level by float control 50 as described for Figure 1. The temperature sensing element 36a is located at the outlet of the vacuum tank and regulates heat input to the heater 44a situated in water body 20a. Relay 38 actuates the heating element 44a, as in Fig. 1.

A model system of the Figure 1 apparatus, not including the heater or the radiator system 32, 34, 44, produced a temperature differential of 38°F. within a few hours and maintained it for three days at an ambient air temperature of 83°F. The system was operated at an internal pressure of 150 mm. Hg, and at a flow rate of 80 air changes per hour through a cylindrical vacuum tank having a total volume of 2.3 liters. After bubbling through the water, the air was directed downwardly over the evaporator by a cap overlying the open top of the evaporator. Water lost by evaporation was supplied manually through a needle valve. Insulation used was minimal; about ¼ inch thickness of Dacron (Trade Mark) polyester covered the vacuum tank and the same thickness of cotton was used on the inlet heat exchanger. With better insulating and a larger unit having a more advantageous surface to volume ratio, calculations demonstrate that the same or still greater differentials can be obtained with fewer air changes.

Particular use for such apparatus is in the storage and transporation of green bananas which benefit by storage at approximately 58°F. with at least one change of air per hour. Full cooling capacity should thus be sufficient, for banana storage, to maintain a differential temperature of up to 62°F. at 120°F. ambient air temperature with increasing heat input capacity for each degree reduction of ambient air temperature up to a total heat input capacity to maintain a differential temperature of 78°F. at −20°F. ambient temperature, based on ambient air temperatures which are likely to be encountered during shipment from the tropics to northern cities in winter time.

Thus as above described, a controlled refrigerated storage environment conducive to preservation of stored metabolically active matter is produced, without the use of closed cycle refrigeration, by expanding atmospheric air and raising its relative humidity by passing it through a body of water while heating the body of water so that the air is cooled by its expansion and by evaporation of said water only to a preservation-conducive temperature and flowing the cooled expanded water-saturated air around the stored matter to sweep away gaseous products of metabolic reaction emitted from said matter. Heat input to the water is made responsive to cooling of the air in the vacuum chamber below a preservation-conducive temperature level and may be via an electric resistance element, e.g., immersed in the body of water, by heat exchange from an oil, water or air cooling system of a vacuum pump which serves as the air expansion means or from atmospheric air.

WHAT WE CLAIM IS:—

1. A method of creating and maintaining a gaseous atmosphere at a predetermined temperature, sub-atmospheric pressure and high relative humidity in a storage chamber for preserving organic matter such as fruit, meat, vegetables, other edible food, plants and flowers, from which gases may respire, the method comprising bringing ambient air to the required temperature, pressure and relative humidity by causing the ambient air to flow through a restricted opening while reducing the pressure of the air, expanding the air and reducing the relative humidity thereof, causing the expanded air to flow into contact with water to evaporate the water, the expansion of the air and evaporation of the water cooling and humidifying the air, causing the humid air to flow through the chamber, and simultaneously removing humid air and gases of respiration of said matter from the chamber, wherein the cooling effect of the expansion and evaporation

is modified by changing the temperature of the water when the temperature in the chamber tends to depart from the predetermined temperature.

2. A method according to claim 1 including the step of exchanging heat between ambient air flowing to the restricted opening and air removed from the chamber.

3. A method according to either claim 1 or claim 2, wherein a space is provided adjacent the chamber and separated therefrom, and ambient air is introduced into said space where it expands, is cooled and humidified, and said cooled and humidified air is supplied from said space to said chamber.

4. A method according to claim 3, wherein said space is enclosed, and said air in said space is in heat exchange relation with said water before the air expands, is cooled and humidified.

5. A method according to any of the preceding claims, wherein air is removed from the chamber at a rate sufficient to remove deleterious gaseous respiration products from the matter being preserved therein.

6. A method according to any of the preceding claims, wherein the air is withdrawn from the chamber at a rate sufficient to cause at least one change per hour of the air in the chamber.

7. A method according to any of the preceding claims, wherein the pressure of the air in the chamber is maintained at or between 4 and 400 mm Hg absolute.

8. A method according to any of the preceding claims, wherein the cooling effect of the expansion and evaporation is modified by changing the rate of flow of air through the chamber.

9. A method according to any of the preceding claims, wherein the temperature of the air in the chamber is maintained at or between 32°F and 58°F and the relative humidity is maintained near but less than saturation at the corresponding temperature therein.

10. A method according to claim 9, wherein the chamber contains green bananas and the temperature of the air in the chamber is maintained at 58°F.

11. A method according to any of the preceding claims, including causing heat exchange between the water and air in the chamber.

12. A method according to any of the preceding claims, including drying the air before it flows through the restricted opening.

13. Apparatus including a storage chamber for organic matter such as fruit, meat, vegetables, other edible food, plants and flowers from which gases may respire, and means for creating and maintaining a gaseous atmosphere in the storage chamber at a predetermined temperature, sub-atmospheric pressure and high relative humidity for preserving organic matter when in the chamber, the gaseous atmosphere maintaining means comprising pump means for removing air and gases of respiration from the chamber and for drawing fresh air into the chamber, a restricted opening through which ambient air will be caused to flow by the pump means to reduce the pressures of the air, cause the air to expand and reduce the relative humidity thereof, means for receiving a supply of water arranged so that expanded air from the restricted opening and to be supplied to the chamber will be brought into contact with water in the water receiving means to humidify the air, the arrangement being such that the expansion of the air and evaporation of the water will cool the air, and means responsive to the temperature in the chamber for modifying the cooling effect from the expansion of the air and evaporation of the water when the temperature of the air in the chamber tends to depart from the required temperature.

14. Apparatus according to claim 13, including means for exchanging heat between air flowing to the restricted opening and air removed from the chamber.

15. Apparatus according to either claim 13 or claim 14, including a space provided adjacent the chamber and separated therefrom, wherein the restricted opening and water receiving means are provided in the space, and means are provided for conducting humidified air from the space into the chamber.

16. Apparatus according to claim 15, wherein said space is enclosed, and means are provided for bringing air in the space into heat exchange relation with water when in the water receiving means upstream of the restricted opening.

17. Apparatus according to any of claims 13 to 16, wherein the gaseous atmosphere maintaining means are operable to maintain the pressure in said chamber at or between 4 and 400 mm Hg absolute.

18. Apparatus according to any of claims 13 to 17, wherein the gaseous atmosphere maintaining means are operable to maintain the temperature in said chamber at or between 32°F and 58°F and to maintain the relative humidity near but less than saturation at the corresponding temperature therein.

19. Apparatus according to any of claims 13 to 18, including means for exchanging heat between the air in the chamber and water in the water receiving means.

20. Apparatus according to any of claims 13 to 19, including a constricted discharge nozzle through which humidified air will flow into the chamber and arranged to discharge air therefrom against a heat exchange

unit in the chamber and in communication through a closed circuit with the water receiving means, the closed circuit including a pump for circulating water through the closed circuit.

21. Apparatus according to any of claims 13 to 20, wherein the means for modifying the cooling effect include means for adjusting the restricted opening.

22. Apparatus according to any of claims 13 to 21, wherein the means for modifying the cooling effect include a heat exchanger for heating water when in the water receiving means.

23. Apparatus according to claim 22, wherein the pump means for removing gases from the chamber is an oil seal vacuum pump having circulating sealing liquid and the heat exchanger is arranged for communication with the sealing liquid.

24. Apparatus according to claim 22, wherein the pump means for removing gases from the chamber includes a fluid cooling system and the heat exchanger is arranged for communication with the fluid cooling system.

25. Apparatus according to claim 22, wherein the heat exchanger comprises an electrical resistance heater.

26. Apparatus according to any one of claims 13 to 25, including means for drying air flowing to the restricted opening.

27. A method according to claim 1 substantially as herein described with reference to the accompanying drawings.

28. Apparatus for use in preserving organic matter substantially as herein described with reference to the accompanying drawings.

A. A. THORNTON & CO.,
Northumberland House,
303—306 High Holborn,
London, W.C.1.

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2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

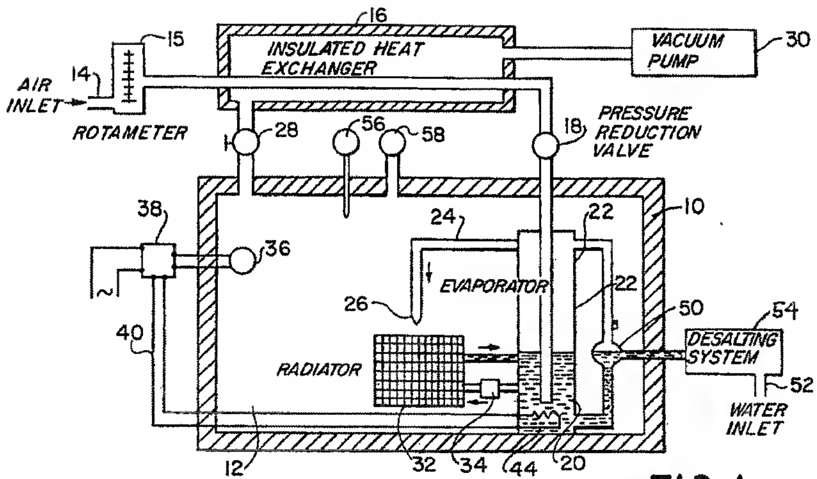

FIG. 1

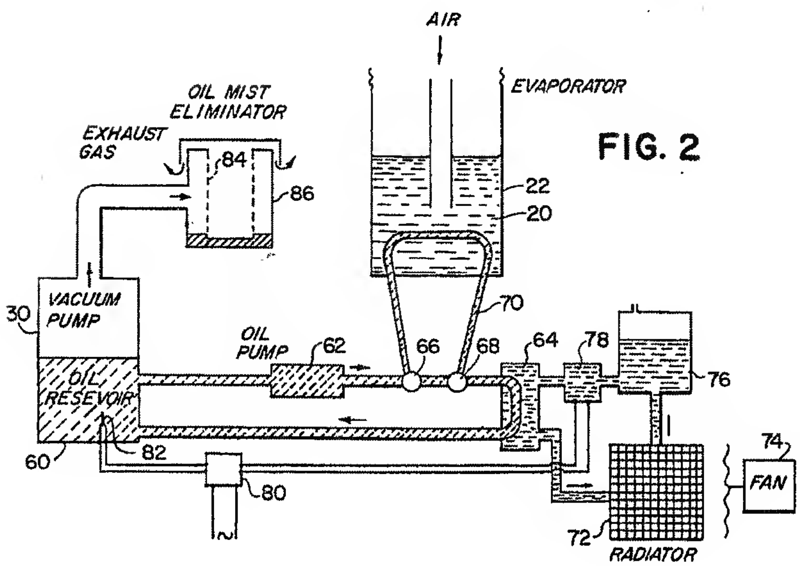

FIG. 2

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Sheet 2

FIG. 3